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Open problems in forward–backward multiplicity correlations in hadron–hadron collisions in the TeV region

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Abstract

Continuing previous work on forward–backward multiplicity correlation properties in proton–proton collisions in the framework of the weighted superposition model of two components (each one described by a negative binomial multiplicity distribution) with the addition of the leakage parameter which controls clan spreading from one hemisphere to the opposite one, we examine E735 data on the c.m. energy dependence of the total correlation strength and of the forward variance at fixed total multiplicity. A comparison with the Chou–Yang approach to the problem is presented and extrapolations of the mentioned variables at LHC c.m. energy in possible scenarios in the new energy domain are discussed.

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As discussed in Ref. [1], the c.m. energy dependence of the forward–backward multiplicity correlation (FBMC) strength, b_{total} , in e^+e^- annihilation and pp collisions can be understood as the result of the superposition of two components or classes of events. The two components are, respectively, 2- and 3-jet event classes in e^+e^- annihilation, soft (without mini-jets) and semi-hard (with mini-jets) classes in pp collisions. A general formula was given for b_{total} which does not depend on the specific form of the multiplicity distribution (MD) in each component, but only on the first two moments, the FBMC strength in each component, b_1 and b_2 , and the weight factor, α .

In the case of e^+e^- annihilation, the correct value of b_{total} at LEP energy was reproduced under the experimental conditions $b_{2\text{-jet}} \approx b_{3\text{-jet}} \approx 0$. This fact was

considered as a successful test of the superposition mechanism itself.

The situation was found to be quite different in pp collisions. Here it was shown that the correct energy dependence of b_{total} can be determined by assuming, in addition to the above mentioned parameters, the explicit form of the MD in the soft and semi-hard components (i.e., two negative binomial (NB) MD's with different parameters) and related clan structure, and by introducing the corresponding particle leakage parameters p_{soft} and $p_{\text{semi-hard}}$, which control clan spreading over both hemispheres. The leakage parameter is indeed defined as the fraction of particles within one clan which remain in the same hemisphere where the clan was produced.

Within this framework, the energy dependence of b_{total} was then extrapolated in the TeV region by examining three different scenarios (see [2] for details) characterized by the same soft component struc-

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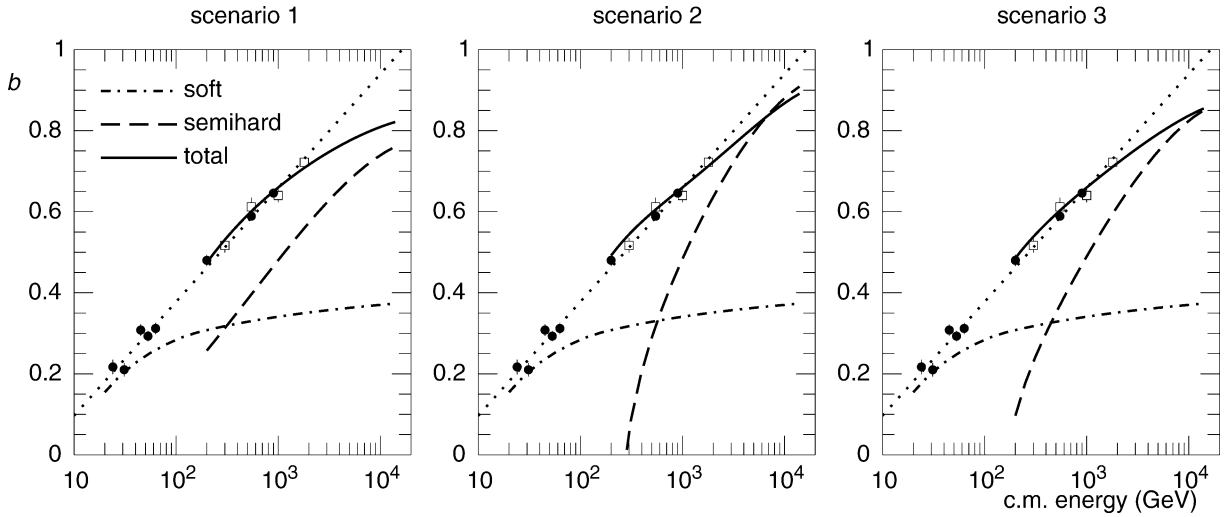


Fig. 1. Energy dependence of the correlation coefficients for each component (soft and semi-hard) and for the total distribution in $p\bar{p}$ collisions. The dotted line is a fit to experimental values [3,4].

ture satisfying KNO scaling, and by different semi-hard component behaviours: (1) obeying again KNO scaling, or (2) with strong KNO scaling violation or (3) with a QCD inspired behaviour. A clear bending of b_{total} was visible in all examined scenarios. It was remarked that an early saturation of b_{total} toward 1 in the semi-hard component would require a fast increase with energy of particle leakage, i.e., a decrease of the corresponding leakage parameter $p_{\text{semi-hard}}$, and would favour strong KNO scaling violation.

The aim of this Letter is to discuss in the mentioned framework the E735 Collaboration results [3] on c.m. energy dependence of the FBMC strength, b_{total} , and of the forward variance at fixed total multiplicity n , $d_{n_F}^2(n)$, obtained at Tevatron. It should be pointed out that

$$b_{\text{total}} \equiv \frac{\langle (n_F - \bar{n}_F)(n_B - \bar{n}_B) \rangle}{\sqrt{\langle (n_F - \bar{n}_F)^2 \rangle \langle (n_B - \bar{n}_B)^2 \rangle}} = \frac{D_n^2 - 4\langle d_{n_F}^2(n) \rangle}{D_n^2 + 4\langle d_{n_F}^2(n) \rangle}, \quad (1)$$

where $\langle \cdot \rangle$ indicates an average over all events, and D_n is the dispersion of the MD. Furthermore, let us introduce the variable

$$\langle z^2 \rangle_n \equiv \langle n_F - n_B \rangle_n = 4d_{n_F}^2(n), \quad (2)$$

where $\langle \cdot \rangle_n$ indicates the average over all events at fixed n . It is clear that variable (2) works at a deeper

level of investigation, being variable (1) related to the average of (2) over all multiplicities. Variable (1) is particularly interesting for global properties of the collisions related to average n .

Variable (1), in the weighted two-component superposition model summarized above, can be expressed as follows:

$$b_{\text{total}} = \left(\alpha \frac{b_1}{(1+b_1)} D_{n,1}^2 + (1-\alpha) \frac{b_2}{(1+b_2)} D_{n,2}^2 + \frac{1}{2} \alpha (1-\alpha) (\bar{n}_2 - \bar{n}_1)^2 \right) \times \left(\alpha \frac{1}{(1+b_1)} D_{n,1}^2 + (1-\alpha) \frac{1}{(1+b_2)} D_{n,2}^2 + \frac{1}{2} \alpha (1-\alpha) (\bar{n}_2 - \bar{n}_1)^2 \right)^{-1}, \quad (3)$$

where the single component FBMC strength is

$$b_i = \frac{2\bar{n}_i p_i (1-p_i)}{\bar{n}_i + k_i - 2\bar{n}_i p_i (1-p_i)}, \quad (4)$$

with $i = \text{soft, semi-hard}$; k is the parameter of the NBMD which is related to the dispersion by $k^{-1} = (D_n^2 - \bar{n})\bar{n}^{-2}$.

Variable (2) in turn can be written as

$$\langle z^2 \rangle_n = 4d_{n_F,1}^2(n) \frac{\alpha P_1(n)}{P(n)} + 4d_{n_F,2}^2(n) \frac{(1-\alpha) P_2(n)}{P(n)}, \quad (5)$$

where

$$P(n) = \alpha P_1(n) + (1 - \alpha) P_2(n) \quad (6)$$

is the total MD, with $P_1(n)$ and $P_2(n)$ the two component MD's, respectively.

Energy dependence of b_{total}

It is found that the points at 1000 and 1800 GeV from E735 Collaboration have the same energy dependence (they lie on the same straight line) as the other data in the GeV region [3]. In order to include the point at 1800 GeV the three extrapolated scenarios for the semi-hard component discussed in Ref. [1] are reexamined. Results are shown in Fig. 1.

In general, one can conclude that the leakage parameter for the semi-hard component, $p_{\text{semi-hard}}$, must decrease, and accordingly particle leakage increase, in all scenarios. To be quantitative, we have found that satisfactory results are obtained by taking the leakage parameter for the soft component energy independent and equal to 0.8, as argued in [1], and taking tentatively $p_{\text{semi-hard}} = 0.84 - 0.07 \log(\sqrt{s}/200)$ for $\sqrt{s} > 200$ GeV; keeping this energy dependence for $p_{\text{semi-hard}}$ at all energies, the curves in Fig. 1 have been extrapolated to 14 TeV. It should be noticed that in scenario 2, characterized by a semi-hard component with strong KNO scaling violation, the FBMC strength becomes less steep with the increase of the c.m. energy and its saturation toward 1 (as that of b_{total}) quicker than in the other two scenarios.

In conclusion, a linear behaviour of b_{total} with c.m. energy is incompatible with our approach above 2.5 TeV in scenario 1, above 3.5 TeV in scenario 2 and above 5 TeV in scenario 3, i.e., the leakage parameter energy dependence cannot be adjusted to such situation in the various scenarios without spoiling the model itself. On the contrary, if such a linear behaviour were found experimentally at LHC, it could be indicative of the onset of a third component (class of events).

$\langle z^2 \rangle_n$ vs. n dependence

Fig. 2 shows experimental data from UA5 Collaboration [4] at 900 GeV in $1 < |\eta| < 4$ together with

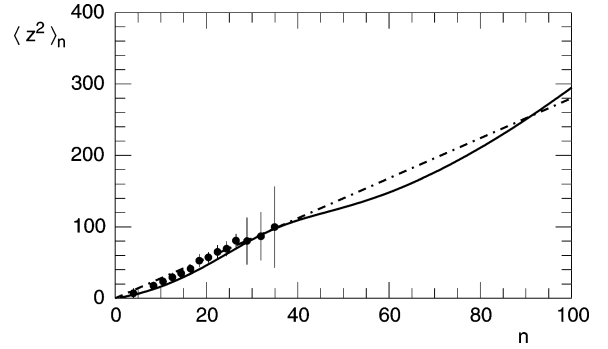


Fig. 2. $\langle z^2 \rangle_n$ vs. n at 900 GeV in the interval $1 < |\eta| < 4$. Data points are from UA5 Collaboration [4], the solid line is the result of our model in $0 < |\eta| < 4$, the dash-dotted line is a linear fit.

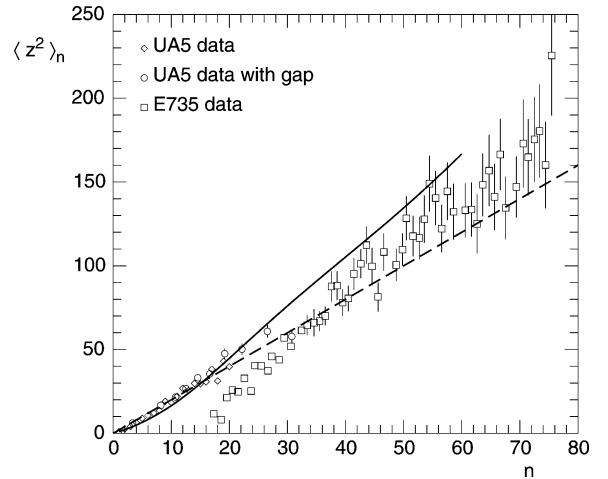


Fig. 3. $\langle z^2 \rangle_n$ vs. n at 546 GeV. Data from [4,5] and [3] are compared with each other, with the prediction of our model (solid line) and with a linear fit (dashed line).

the result of calculations in the present approach (solid line); the dashed line is a linear fit according to the cluster model of Chou and Yang [5], already discussed in [1]. Below $n \approx 40$, where data are available, it is quite hard to distinguish the two model predictions; at $n \approx 40$ our approach shows a “hump”. In view of the lack of sufficiently precise data in this domain, no conclusions can be drawn.

It should be pointed out that at higher c.m. energy (1.8 TeV), the E735 data also show at $n \approx 40$ a qualitative picture like a hump. However, a quantitative comparison is problematic for two reasons:

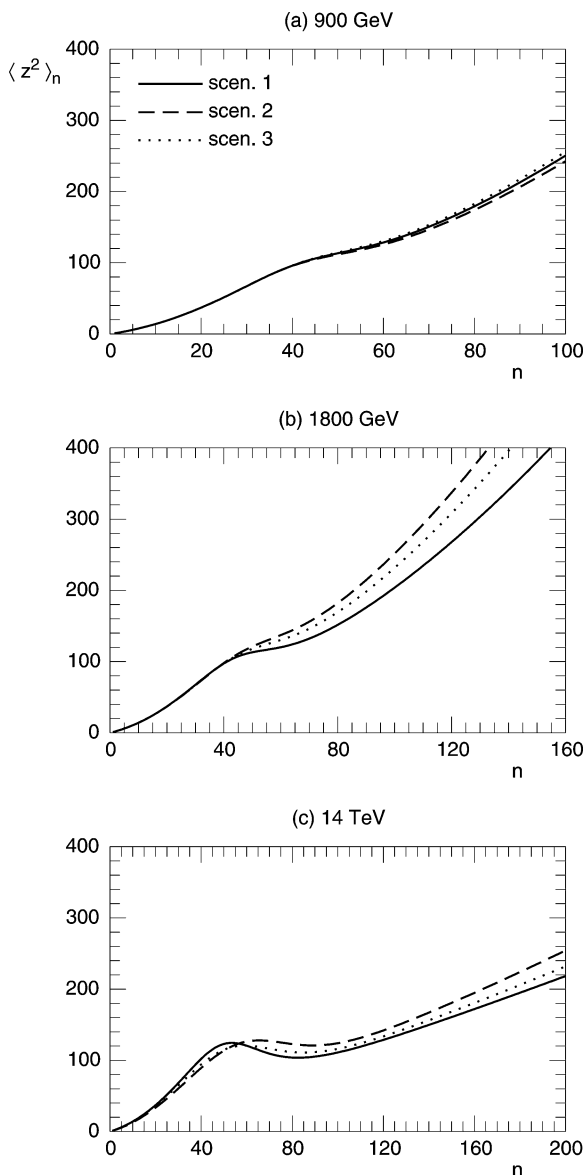


Fig. 4. Results for $\langle z^2 \rangle_n$ vs. n in full phase-space for different c.m. energies in different scenarios.

- (a) our calculations are based on extrapolations in full phase-space while data refer to the interval $|\eta| < 3.25$, for which no MD has been published (on the contrary, available MD data from UA5

allowed us to compare our model's predictions at $Sp\bar{p}S$);

- (b) at lower c.m. energy (546 GeV, see Fig. 3) we noticed a discrepancy between UA5 results [6] and E735 results; for completeness, in Fig. 3 our results and a linear fit are also shown.

The three scenarios we have discussed previously do not show any remarkable difference in the GeV region as far as the $\langle z^2 \rangle_n$ vs. n dependence is concerned (see Fig. 4(a), where $\langle z^2 \rangle_n$ vs. n is plotted in the three scenarios at 900 GeV in full phase-space). In Fig. 4(b) the same plot is shown at 1800 GeV. Differences in the three scenario predictions become more evident for n larger than 40 and the hump is more visible. In Fig. 4(c) at 14 TeV the hump becomes even more visible and in addition its maximum varies with the scenario.

In conclusion, the behaviour of $\langle z^2 \rangle_n$, i.e., the two different sides of the hump appearing in the plot of $\langle z^2 \rangle_n$ vs. n , which is remarkable at 1800 GeV, confirms in our view the presence of two components (samples of two classes of events) and the importance of the role of the semi-hard component at this energy. The question remains whether this is also the indication of the occurrence of a phase transition [7].

Acknowledgement

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